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The use of spatial tools in the study of *Schistosoma mansoni* and its intermediate host snails in Brazil: a brief review

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Abstract. The rapidly increasing number of spatial studies and the complexity of schistosomiasis transmission dynamics in Brazil indicate that surveillance and control programmes can benefit from the spatial approach, not only in areas susceptible to the introduction and establishment of new transmission foci but also in areas experiencing declines in schistosomiasis transmission. Several additional areas amenable to, or requiring, spatial research are identified. This paper reviews spatial studies of schistosomiasis in Brazil with a focus on the application of spatial tools in epidemiological, disease ecological, control and several additional areas in schistosomiasis research.

Keywords: schistosomiasis, *Biomphalaria* spp., geographical information system, mapping, Brazil.

Introduction

Computer-assisted mapping and spatial analysis of infectious diseases have seen major advances in recent years. The appropriateness of using geographical information system (GIS), global positioning system (GPS) and remote sensing (RS) tools in the study of schistosomiasis and other vector-borne diseases and progress in their application in epidemiological studies and control programmes have been reviewed by Malone et al. (2001a). The dynamic nature of vector-borne diseases and the need for rapid decision making, as well as their intimate linkage to the physico-biotic and human environment, demonstrated by mathematical modeling, have facilitated the development of more accurate and rapid spatial techniques than those possible with traditional manual mapping and spatial analysis methods (Morel, 2001). Heterogeneity in both intermediate host snail distribution and human behaviour associated with risk of infection (water contact behaviour) are instrumental in determining schistosomiasis transmission dynamics (Woolhouse et al., 1991; Brooker and Michael, 2000) and provide many opportunities for spatial studies.

In Brazil, where traditional manual mapping methods had been used to document the spread of schistosomiasis and its intermediate snail hosts since the 19th century (Meira, 1949; Kvale, 1981; Machado, 1982), the use of intermediate level spatial analytic tools predates the arrival of GIS and GPS. Barreto (1993), for example, used a computerized digitizer to plot dots on x and y coordinates for individual study households, which he then correlated with socio-economic and epidemiological data to determine schistosomiasis risk factors at the community level. In Branquinha, another town in the hyperendemic northeast of Brazil, Kloetzel (1989) used grid diagrams, which he overlaid on a town map, to identify and spatially correlate poor neighborhoods with high schistosomiasis prevalence. This analysis revealed that infection foci persisted after chemotherapy of all children, indicating the strong link between schistosomiasis and poverty. Computerized spatial studies have been carried out

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during the last 10 years in increasing numbers in the areas of snail distribution, risk of infection, and schistosomiasis control. The rapid increase of spatial studies of schistosomiasis using GIS, GPS and RS tools in Brazil is reflected in the exponential increase in the number of presentations at the biannual schistosomiasis symposia held in this country since the Symposium in Rio de Janeiro in 1999. In 2000, Brazil became part of a global network of collaborating organizations and individual scientists dedicated to the development of computer-based models suitable for improved control programmes for schistosomiasis and other snail-borne diseases (Malone et al., 2001b).

The objective of this review is to briefly summarize the literature of epidemiological, ecological and intervention studies in Brazil using the spatial approach and to point out opportunities for studies in some understudied areas of schistosomiasis research.

Epidemiological and disease ecological studies

Spatial studies of risk of schistosomiasis using GIS, GPS and RS tools have proceeded along two main lines, namely description of the distribution of infection or risk of infection and secondly the spatial modeling of infection risk. Descriptive mapping of schistosomiasis has been used to elucidate the heterogeneity of infection and risk of infection at the individual, neighbourhood, and regional levels. Kloos et al. (1998, 2001) associated both the presence of a water supply in the household and low socio-economic status with high *Schistosoma mansoni* infection rates both before and after the installation of a piped water supply in a small rural village in northern Minas Gerais State. This is the only study to map exposure risk based on direct observation of human water-contact patterns in a small rural village in Minas Gerais (Kloos et al., 1998, 2001). Exposure risk in Brazil has traditionally been studied through interviews, which are more cost-effective, in a country where private ownership of rural land and water resources causes human water contact patterns to be more dispersed at more sites than in Africa (Kloos et al., 1998, 2006; McClennon et al., 2004).

The recent shift in emphasis, from area-wide schistosomiasis control programmes to more focused interventions targeting high-risk individuals and communities in both highly endemic areas and in low transmission areas (WHO, 2001; Savioli et al., 2004), makes spatial analyses at the local and household levels essential (Brooker and Michael, 2000). In Brazil, several epidemiological studies in Melquiades rural area in Minas Gerais established the crucial role of the household as a risk group in regard to behavioural and infection parameters (Bethony et al., 2001, 2004; Gazzinelli et al., 2001). In Virgem das Graças, another rural area in northern Minas Gerais, distinct spatial patterns of schistosomiasis were noted in a household-based study using a pre-/post-treatment design. Pre-treatment household prevalence and egg counts were highly concentrated in some households and neighbourhoods and inversely related to post-treatment IgE levels. In the single village with a central water supply, low exposure risk was associated with low pre-treatment infection rates (Fig. 1) but did not, like distance from homes to the streams, contribute to the sharp decline of infection rates after chemotherapy (Gazzinelli et al., 2006). These results demonstrate the production and antiparasitic effect of high levels of IgE in *S. mansoni* infection and their impact on the focality of infection at the household level.

Longitudinal spatial studies using patient data collected by the health services, although underreporting the number of *S. mansoni* infections, has provided some useful information for the planning of control programmes. Most longitudinal epidemiological studies and historical studies of the spatial distribution of hospital admissions and deaths from schistosomiasis in Brazil show a long-term decline (Katz, 1998) but several investigators have also reported increased prevalence for some periods or some areas. In Pernambuco State, for example, the number of hospitalized schistosomiasis cases from the interior of that State and in the São Francisco River Valley increased in 1999 and 2000 after a

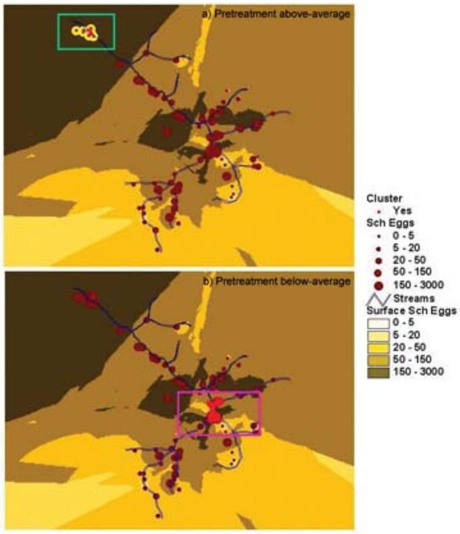

Fig. 1. *Schistosoma mansoni* egg counts in Virgem das Graças, Brazil. a: pre-treatment above-average counts ($p = 0.001$); b: below-average counts ($p = 0.005$).
Source: Gazzinelli et al. (2006).

decline between 1992 and 1998 (Resendes et al., 2005). In Bahia State, no significant changes were noted in the distribution of schistosomiasis at the municipality level between the 1950s and 1980s, even though the overall prevalence had declined from 15.6% to 9.5%. This decline was not associated with the administration of community-based chemotherapy, and in some municipalities prevalence even increased, apparently due to population dynamics and spatial inequalities in the urbanization process, which create conditions favourable to the spread of schistosomiasis and the establishment of new foci (Carmo and Barreto, 1994). The vulnerability of Brazilian towns to schistosomiasis has been reported elsewhere (Mott et al., 1995; Ximenes et al., 2003; Kloos et al., in press). Health facility-based schistosomiasis and census-based demographic data, although being increasingly used for surveillance purposes as a result of decentralization of the health services in 1999 to the municipalities, can only give a broad indication of spatial and temporal trends. Existing data may be insufficient to construct a surveillance index for serious forms of the disease unless a systematic, standardized data collection system is implemented (Barbosa et al., 2005; de Farias et al., 2007).

A considerable number of *S. mansoni* host snail distribution maps have been prepared by epidemiologists and malacologists over the years. The relatively large number of *S. mansoni* intermediate hosts in Brazil, all with different degrees of susceptibility to infection, together with the continued spread of snails into new localities and the large number of potentially suitable snail habitats have fostered a strong and persistent interest in the geographic and temporal distribution of different species of *Biomphalaria*. Published studies range in scale from the South American subcontinent and Brazil (Paraense, 1986, 2001; Souza et al., 1997) to the State (Bavia et al., 2001; Souza et al., 2001) and community (Souza et al., 1998; Thiengo et al., 2001; Kloos et al., 2004; Tibirica et al., 2006) levels. Most spatial studies mapped snail infections or correlated snail distributions to schistosomiasis prevalence with the objective of identifying high-risk areas, communities and human-water contact sites (Carvalho et al., 2003; Barbosa et al., 2004; Kloos et al., 2004; Araújo et al., 2007). GPS/GIS-generated maps and spatial analyses (Kloos et al., 2004, 2006; Guimarães et al., 2005) are rapidly replacing manually-drawn maps of snail occurrence and infection (Freitas, 1968). The presence of endemic and hyperendemic schistosomiasis in many Brazilian cities (Mott et al., 1995; Ximenes et al., 2003), which usually provide more diverse exposure risk and socio-economic levels than rural communities (Kloos et al., 2006), highlights the need for further studies of urban schistosomiasis.

Spatial analysis of mortality due to schistosomiasis has been hampered by the fact that it is not a reportable disease and deficiencies in the information system. In spite of these impediments, Almeida et al. (2003) found spatial clustering of schistosomiasis-related mortality and spatial associations with socio-economic indicators in the forest zone in the State of Pernambuco, the second highest ranking State in schistosomiasis prevalence in Brazil (15.2%), and called for improvements in the information system towards generating more reliable mortality data.

Modeling the distribution of *Biomphalaria* and schistosomiasis risk by integrating climate, soil, vegetation and socio-economic data using satellite-based RS and GIS systems is a new genre of disease-ecological studies which can contribute to assess the suitability of different regions and localities for snail species (Kristensen et al., 2001). The invasion of different snail hosts and the spread of schistosomiasis into new areas is a major concern in Brazil, where various snail species continue to spread into new areas as a result of dam construction, irrigation development and new settlement projects. By using satellite-derived regional agro-climatic, vegetation and surface temperature maps, together with schistosomiasis prevalence and intermediate host snail distribution data for 270 municipalities in Bahia in a GIS environmental risk assessment model, Bavia et al. (2001) identified several physico-environmental and demographic factors in the distribution of this parasitosis. Currently a similar spatial model is being developed in Minas Gerais (Dutra et al., 2005; Freitas et al., 2005; Silveira et al. 2005). The development of such multivariate models, both at the regional and the community levels, can contribute to identifying high-risk schistosomiasis areas in rapidly developing areas in Brazil and thus facilitate the implementation, management, evaluation and cost-effectiveness of control programmes. State-level studies and investigations in other larger geographical areas and research on geographically, climatically, socio-economically and demographically diverse populations may require up-scaling to provide for replication of spatial associations found, consideration of all the major environmental parameters of an area, and the environmental requirements and limits of tolerance of the endemic snail species (Kristensen et al. 2001).

Schistosomiasis control

Epidemiological and ecological studies using a spatial perspective can effectively contribute to the planning, implementation, surveillance and evaluation of schistosomiasis control programmes. However, few projects have adopted a spatial approach from the beginning as in Rio de Janeiro State, where implementation of a GIS project contributed to the planning, monitoring activities during the surveillance phase of the schistosomiasis control programme at the community level (Moza et al., 2005). The characteristic focality of schistosomiasis distribution, one of the major barriers in the control of schistosomiasis (Crompton et al., 2003), can be efficiently captured and analyzed using spatial tools. Thus, spatial studies can play a major role in the identification, surveillance and control of residual and newly emerging foci in endemic areas experiencing continuous declines in schistosomiasis transmission, also reported from Brazil (WHO, 2001).

Similarly, neither have many studies been carried out on geographic, socio-economic, and health services-related factors with reference to the spatiality of health-seeking behaviour of schistosomiasis patients, nor on the accessibility and utilization of health services. The decentralization of the health services and the correspondingly wider use of municipality health services emphasize the need to identify patterns and constraints in patient-access to, and utilization of, public health services, following established methodologies (Joseph and Phillips, 1984). In Sumidouro municipality in Rio de Janeiro, Soares et al. (2005) associated difficulty of geographical access of the health services with higher rates of schistosomiasis. Their longitudinal, interdisciplinary study, using qualitative and quantitative methods, including GIS, addressed complex socio-economic, environmental and ecological problems which increased the vulnerability of the population to multi-parasitism and interfered with the health-seeking behaviour and health services utilization of infected persons. Our research group at the Centro de Pesquisas René Rachou has begun a comparative study of the accessibility and utilization of health centers by *S. mansoni*-infected people in a rural area in the northern part of Minas Gerais State.

Other potential applications of the spatial method

An excellent review of the literature by Paraense (2001) on the epidemiological and laboratory evidence of variable susceptibility of different species of *Biomphalaria,* and compatibility between schistosome and snail strains from different parts of Brazil, indicates the need to analyze the spatial distribution of different snail species and their schistosome infectivity status in the evaluation of actual and potential transmission risk. Paraense's finding that the westward diffusion of schistosomiasis in São Paulo State was prevented by the replacement of *B. tenagophila* by *B. occidentalis* in the western part of that state highlights the epidemiological value of longitudinal snail surveys and mapping of the changing distribution of different snail species.

Recent developments in molecular approaches to the identification of *S. mansoni* transmission sites have produced detection systems that are more sensitive than standard screening of snail hosts by cercarial shedding (Melo et al., 2006), which may increase the reliability of identifying transmission sites. Similarly, mapping of genetic markers related to the susceptibility of different species of *Biomphalaria* in Brazil may provide new information on the macro- and micro-distribution of snail strains susceptible and resistant to *S. mansoni* infection (Oliveira et al., 2005).

In Brazil and other countries with declining schistosomiasis prevalence and intensity, the identification and spatial analysis of the distribution of high-risk populations such as school-aged children not attending school and pre-school children may contribute to surveillance activities and control programmes focused on difficult-to-reach populations and individuals (WHO, 2001; Crompton et al., 2003). Two other understudied and high-risk environments, i.e. large reservoirs (Fernandez et al., 2003) and tourist resorts (Eng et al. 2003; Barbosa et al., 2004; Araújo et al., 2007) require careful surveillance of the intermediate host snail occurrence and human infections. There is no doubt that such studies will be facilitated by the use of GIS and GPS systems.

Conclusions

Spatial epidemiological and disease ecological studies of intermediate host snails using GIS, GPS and RS tools have increasingly been carried out in Brazil during the last 10 years. They have provided new insights into *S. mansoni* transmission and other information facilitating the development of appropriate and cost-effective interventions. The general decline of schistosomiasis in response to chemotherapy, socio-economic development and improvements in domestic water supply and sanitation on one hand, and the diffusion of the parasite into water development projects and new settlements harbouring, or susceptible to, the spread of intermediate host snails on the other, reflects a dynamic, complex environment amenable to spatial studies and modeling efforts. Accessibility and utilization of the public health services by schistosomiasis patients, which can be evaluated using spatial tools, are urgently needed in view of the focus of the Brazilian schistosomiasis control programme on chemotherapy (WHO, 2001). The identification of high-risk individuals and groups, modeling of the distribution of snail intermediate host snails and transmission risk, as well as the development of new molecular approaches to assessing transmission potential are of particular interest for control purposes. However, they will require reliable data and the studies must be carried out at scales and in temporal frames appropriate for control programmes to be of optimal usefulness.

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